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SOME RESULTS OF SPECTROPHOTOMETRIC MEASUREMENTS OF THE EARTH FROM THE "SOYUZ-7" SPACECRAFT

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ABSTRACT. It is found that spectrophotometric measurements from "Soyuz 7" made it possible to compare data on reflectivity, radiation temperature, and other reflective and radiative characteristics of the Earth's surface.

The first experiments on spectrophotometric measurements of the twilight /1084** halo of the Earth from space were made in January, 1969, during the flight of the "Soyuz-5" spacecraft. The basic results of this experiment were discussed in the papers [1-4]. With the combined flight of the spacecrafts "Soyuz-6,7,8", the program of complex optical experiments was broadened to include the solution of the following basic problems:

1. Spectrophotometric measurements of the sun and the twilight halo of the Earth's atmosphere under various observation conditions, solar radiation, and the position of the observer in space in order to study the brightness and colors of the halo, and to determine the vertical distribution of various atmospheric components.

2. Spectrophotometric measurements of various natural formations with the goal of determining the feasibility of identifying them from spectral reflecting characteristics, measured from space.

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3. Synchronous execution of a complex program of earthbound and airborne optical investigations of the atmosphere and of various types of underlying surfaces in the region under the satellite for obtaining data which would characterize the spectral transmission function of the atmosphere, spectra, and spectral contrasts of natural formations as a function of the basic optical parameters.

Spectrophotometric measurements of the twilight atmosphere and the underlying surfaces ~~were~~ made from the "Soyuz-7" spacecraft by means of a modified manual RSS-2 spectrograph [5]. The input telescope objective simultaneously focused the image of the distant object at the input slit of the spectrograph (spectrograph channel) and directly on the photographic film (photographic channel). The focal distance was f — 135 mm; the relative opening was D/f = 1:4. For this model of the spectrograph, the linear dispersion was 166 Å/mm, the spectral width of the slit was 50 Å, and the spectral range for measurements was 430 to 690 mμ. The limiting angular resolution of the spectrographic channel was 2 minutes of arc; that of the photographic channel was 4 minutes. The spectra were reduced using the method described in [4].

This experiment [1] did not evaluate the effect of the spectral transmission of the solar radiation through the spacecraft illuminator. Evaluation of this quantity ahead of the spectrograph objective was carried out by installing a light-scattering filter with known optical characteristics. Then the apparatus was pointed at the Sun.

Photographic film in the spectrograph was exposed to a standard source and the Sun using the light-scattering filter. The darkening densities of the photographic films from the two sources were compared. The comparison made it possible to find the spectral illumination of a unit area, which gave the solar illumination transmitted through the spacecraft illuminator.

During the group flight of the "Soyuz-6,7,8" satellites, spectrophotometric measurements of the twilight halo were taken on the 87th revolution of "Soyuz-7", at 2147 hrs Moscow time as the sun set. The geographic coordinates of the spacecraft were 23.18° north latitude and 23.39° east longitude (in the region of northeast Africa). The altitude of the orbit at the moment of the experiment was approximately 218 km. /1085

The results of the experiment were compared with similar data taken during the flight of "Soyuz-5". The comparison showed that the qualitative behavior of the monochromatic curves of the halo brightness was the same for both experiments. However, the absolute values of the brightness in the first experiment [1] were 2 to 3 times smaller (λ = 650 mμ). The monochromatic brightness curves of both the previous experiment and the current experiment showed an absence of noticeable depressions caused by aerosol layers, localized at various levels in the atmosphere.

This communication also presents data on the spectra of various natural surfaces, which were obtained on October 13, 1969 from "Soyuz-7" on the trajectory from the Arabian peninsula to the Aral Sea. Spectrophotometric measurements of various parts of the Earth's surface were made in a short period of time from 1319 hrs to 1329 hrs, Moscow time, for a solar height of 35-50°.

During the flight of "Soyuz-7" spectra were obtained on the following identified types of natural surfaces: 1) thick clouds, 2) thin clouds, 3) rocky wilderness, and 4) cloud shadows (Figure 1a). Continuous and dense cumulus and stratocumulus clouds are characterized by a maximum brightness in the range of 0.20 to 0.24 watt/m^2·mμ·steradian in a wavelength range of 440 to 580 mμ (Curve 1, Figure 1a). The brightness significantly decreases to 0.14 to 0.14 watt/m^2·mμ·steradian in the orange-red part of the spectrum for λ = 580 to 690 mμ. Thin clouds of the high-altitude stratus and stratocumulus types at various levels give an integral image for a cloud layer and for shaded surface. This type of surface has little effect on the spectral distribution of the brightness, but its absolute brightness is lowered to

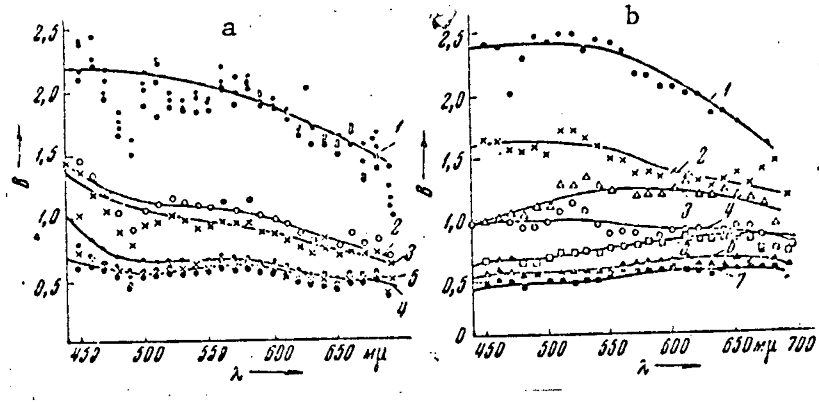

Figure 1. Curves of Spectral Brightness B (watt/m^2·mμ·steradian) for ten natural surfaces obtained on October 13, 1969 during the flight of the "Soyuz-7" spacecraft. a - from the spacecraft: 1 - dense clouds; 2, 3 - thin clouds; 4 - surface of the desert in the northern part of the Arabian peninsula; 5 - surface of the desert on the Ust Urt plateau at the eastern bank of the Caspian Sea; b - from an aircraft: 1 - thick clouds, 2 - thin clouds, 3 - sand, 4 - salt marsh, 5 - rocky wilderness, crossed by dirt roads, 6, 7 - rocky wilderness.

0.12 to 0.14 watt/m^2·mμ·steradian in the interval λ = 440 to 480 mμ, and to 0.07 to 0.1 watt/m^2·mμ·steradian in the interval λ = 580 to 690 mμ (Curves 2 and 3, Figure 1a).

The rocky wilderness of the Ust-Urt plateau is composed of limestone and is covered with a rough gray loamy stoney soil. In places there is takyr soil and thin dusty-sandy deposits. The plant covering is sparse, and has little effect on the spectrum of the landscape. Underlying surfaces of this type yield spectral brightness curves with very weak spectral intensity changes in the range 0.05 to 0.07 watt/m^2·mμ·steradian (Curves 4 and 5 in Figure 1a).

Finally, it is interesting to analyze the darkest, spectrophotometrically analyzed surfaces — regions of light shadows from clouds. Since the shadows were discontinuous, their brightness was much lower than was the rocky wilderness (0.04 to 0.05 watt/$m^2 \cdot m\mu \cdot$steradian). The differences were significantly less in the blue-green region of the spectrum than in the red-orange region.

The spectral contrasts were calculated from data given above on spectral brightness in all possible combinations of natural surfaces (Figure 2a).

The spectral contrasts of the cloud density and the partially shadowed surface of the rocky wilderness reached maximum values of k = 0.77 for λ = 630 mμ. This contrast was somewhat lower in the blue-green region, where k = 0.62. The spectral contrasts of the dense cloudlines and of the rocky wilderness also gave high absolute values of k between 0.6 - 0.7. The changes in the contrasts were the same over the entire curve or decreased in the short-wavelength part of the spectrum (Curves 1 and 2 in Figure 1a). The spectral contrasts for the thin clouds and the rocky wilderness had an analogous brightness pattern. However, the absolute values of the contrast decreased /1087 to about 0.4 (Curves 3 and 5, Figure 2a). Moderate contrast values arose from thick and thin clouds (Curve 4 in Figure 2a). The shape of the curve was monotonic, with variations of k in the range of 0.40 to 0.45. The spectral contrast of the illuminated and shadowed rocky wilderness was also rather small ($k \approx 0.3$). Here the contrast was significantly decreased in the short-wavelength region of the spectrum, and increased in the long-wavelength region (Curve 6, Figure 2a). The contrasts between distant parts of the rocky wilderness were the least, k = 0.05 to 0.15 (Curve 7, Figure 2a). The contrast was higher in the green-blue region of the spectrum for λ = 520 mμ, as well as in the red region for λ = 660 mμ.

These results were compared with simultaneous measurements of the brightness and the contrasts, which were made with analogous equipment (RSS-2) in an airplane flying over the Ust-Urt plateau at the "meeting point" of the

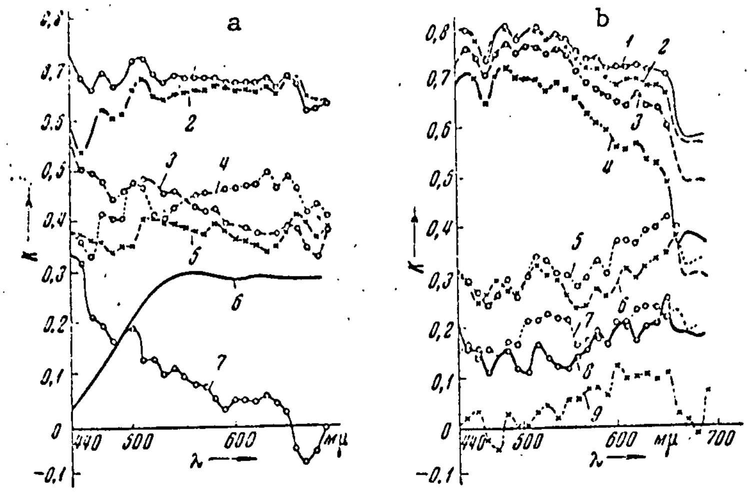

Figure 2. Spectral contrast (K) curves for natural surfaces. These curves were obtained from spectrophotometric data from the flight of the manned spacecraft "Soyuz-7" on October 13, 1969. a - from the spacecraft: 1 - dense clouds over the Arabian desert, 2 - thick clouds over the Ust-Urt desert, 3 - thin clouds over Ust-Urt, 4 - thick clouds and thin clouds, 5 - thin clouds over the Arabian desert, 6 - illuminated Arabian desert, 7 - illuminated desert, partially shadowed (Ust-Urt). b - from an aircraft: 1,2 - thick clouds over a rocky wilderness, 3 - thick clouds over loamy rocky wilderness, crossed by roads, 4 - thick clouds over a loamy-stoney wilderness, 5,6 - loamy-rocky wilderness, crossed by roads — rocky wilderness, crossed by roads, 7 - loamy-stoney wilderness — loamy-stoney wilderness, crossed by roads, 8 - loamy-stoney wilderness — rocky wilderness, 9 - two sections of the rocky wilderness on the Ust-Urt plateau.

spacecraft and the scientific-research airplane. Spectrophotometric measurements were made from the satellite at an altitude of 220 km, and from the airplane at about 2.7 km. Comparison of the satellite results (Figures 1a and 2a) and the airplane results (Figures 1b and 2b) for the measured spectral brightness and contrasts of the same types of underlying surfaces show that the effect of the haze on the optical characteristics was small as compared with the measurements made at 2.7 km. The haze effect is more important in the short-wavelength region of the spectrum, as should be expected. In the long-wavelength region, the solar radiation scattered by the atmosphere above 2.7 km only slightly affects the absolute brightness values of natural surfaces.

In conclusion, it should be noted that the shape of the spectral brightness curves of natural surfaces makes it possible to differentiate several types of natural formations from their spectra, which are measured from spacecraft. It should also be emphasized that the atmosphere distorts the shape of the spectral brightness curves and lowers the spectral contrasts. However, the optical density of the Earth's atmosphere is not very large, in the absence of clouds. Thus it is possible to compare data on reflectivity, radiation temperature, and a combination of other reflective and radiative characteristics of underlying surfaces. These comparisons give a rather precise differentiation of natural formations based on their spectra.

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